Optimal Asset Distribution for Environmental Assessment and Forecasting Based on Observations, Adaptive Sampling, and Numerical Prediction

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LONG-TERM GOAL

The long-term goal is to enhance our understanding of coastal oceanography by means of applying simple dynamical theories to high-quality observations obtained in the field. My primary area of expertise is physical oceanography, but I also enjoy collaborating with biological, chemical, acoustical, and optical oceanographers to work on interdisciplinary problems. I collaborate frequently with numerical modelers to improve our predictive capabilities of Navy-relevant parameters in the littoral zone.

OBJECTIVES

The objective of this Multi-University Research Initiative (MURI) grant, subtitled, “The Adaptive Sampling and Prediction System (ASAP)” is to learn how to deploy, direct, and utilize autonomous vehicles [and other mobile sensing platforms] most efficiently to sample the ocean, assimilate the data into numerical models in real or near-real time, and predict future conditions with minimal error. The scientific goal is to close the heat budget for a control volume surrounding a three-dimensional coastal upwelling center, and identify via the magnitude of the terms the relative importance of the surface fluxes, boundary layer processes, alongshore advection, and mesoscale interactions in determining the temperature changes within the box.

APPROACH

The mobile assets for this project included 10 gliders (6 Slocum vehicles from WHOI and 4 Spray vehicles from SIO), 3 propeller-driven vehicles (DORADO from MBARI and 2 Odysseys from MIT), a research aircraft (NPS TWIN OTTER) and several support ships (SHANA RAE, POINT SUR, ZEPHYR, SPROUL, NEW HORIZON). Given these resources and the objectives above, a control volume (Figure 1) was selected for the 2006 experiment. The box, approximately 40 x 20 km, enclosed the upwelling center that is of central scientific interest. Six gliders were deployed along “racetracks” within the box and 4 were deployed as “rockers” oscillating back-and-forth along the boundaries, one on each end and two covering the offshore side. Using a combination of autonomous and human-activated control, the gliders were coordinated as a group to optimize the sampling coverage of the control volume in response to the ever-changing current conditions. A pair of bottom-mounted

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acoustic Doppler current profilers (ADCPs) was also deployed along the southern boundary of the box to sample and report the internal wave environment in real time via a Seaweb underwater network.

The real-time observations were ingested into the NCOM, HOPS, and ROMS numerical ocean models each evening for predictive runs for the following day. Assets were then re-allocated to optimize sampling coverage and minimize model predictive error. See also annual report of the same name by Prof. Naomi Leonard of Princeton, for more detail on the coordinated control, adaptive sampling, and numerical prediction aspects of this program.

WORK COMPLETED

The PI's Effort during this evaluation period was on preparing manuscripts for publication. Three manuscripts have been published to date. The first provides an overview of the oceanographic conditions during the ASAP 2006 experiment, as well as model/data comparisons between the three models (HOPS, ROMS, and NCOM) and the moored ADCPs [Ramp et al., 2011]. The manuscript is similar in tone and style to our overview of the AOSN-II 2003 experiment [Ramp et al., 2009]. The second focuses on the poleward propagation of coastally-trapped waves through the study area, which accounts for many of the observed model/data discrepancies [Shulman et al., 2010]. The third describes the wind stress curl and associated upwelling in the ocean from the aircraft observations [Wang et al., 2011]. Work continues on the final paper, targeted at the original project goal of trying to close the ocean heat budget off Point Ano Nuevo thereby illuminating the underlying three-dimensional coastal dynamics. This paper uses both observations and modeling to attack the problem. Collaborator I. Shulman (NRL) has been particularly helpful in this endeavor.

Under ASAP funds we have also supported several other closely related follow-on field programs including the NRL BIOSPACE program in the Monterey Bay, the MBARI Creative and Novel Observing Network (CANON) program, and two undersea networking exercises in the San Francisco Bay (Bayweb I and II).

RESULTS

The wind stress during August 2006 consisted of 3-10 day upwelling favorable events separated by brief 1-3 day relaxations. During the first two weeks there was some correlation between local winds and currents and the three models' capability to reproduce the events. During the last two weeks, largely equatorward surface wind stress forced the sea surface and barotropic poleward flow occurred over the shelf, reducing model skill at predicting the circulation. The poleward flow was apparently remotely-forced by mesoscale eddies and alongshore pressure gradients, which were not well simulated by the models. The small, high-resolution model domains were highly reliant on correct open boundary conditions to drive these larger-scale poleward flows. Multiply-nested models were no more effective than well-initialized local models in this respect.

Despite a successful experiment, it is not obvious that the glider data are good enough to compute the gradients necessary for the heat flux estimates through the boundaries of the box. Work continues to assmilate these data into a numerical model which could subsequently be used for this purpose. Comparisons of the wind stress and heat fluxes at the sea surface using the aircraft data and the COAMPS 3-km atmospheric model are still underway

IMPACT/APPLICATION

All recent Navy METOC publications indicate that autonomous vehicles are the way of the future in battlespace environmental assessment. The Naval Oceanographic Office has already initiated procurement of large numbers of gliders and significant numbers of propeller-driven vehicles. Experiments such as ASAP will help the Navy to learn how to utilize these vehicles most effectively, to maximize the information returned, and to assimilate the data into numerical models for environmental prediction. It has been demonstrated that assimilation of glider data into Navy models improves nowcasts, hindcasts, and 1.0-1.5 d forecasts [Shulman et al., 2009].

TRANSITIONS

The virtual control room (COOP) or its derivatives, developed during ASAP, has been used to support several subsequent Navy field experiments including the MB08 "Oktoberfest" experiment and the Impact of Typhoons on the Ocean in the Pacific (ITOP) experiment. Model improvements (i.e. nested model boundary forcing from HYCOM vs. NCOM) are continually being incorporated into Navy real-time systems.

RELATED PROJECTS

See also ONR Annual Report by ASAP lead investigator Naomi Leonard (Princeton)

NRL BIOSPACE Experiment summer 2008

MB08 "Oktoberfest" ocean color and harmful algal bloom experiment

San Francisco Bayweb I and II, spring and summer 2009, San Francisco Bay - Acoustic networking of ocean sensors in a high-current, high-noise environment.

MBARI CANON Experiment (ongoing)

PUBLICATIONS

Ramp, S. R., P. F. J. Lermusiaux, I. Shulman, Y. Chao, R. E. Wolf, and F. L. Bahr, 2011: Oceanographic and atmospheric conditions on the continental shelf north of the Monterey Bay during August 2006. *Dyn. Atmos. Oc.*, doi:10.1016/j.dynatmoce.2011.04.005.

Wang, Q., J. Kalogiros, S. R. Ramp, J. Paduan, G. Buzorius, and H. Jonsson, 2011: Wind stress curl and coastal upwelling in the area of Monterey Bay observed during AOSN-II. *J. Phys. Oceanogr.*, **41**, 857-887

Shulman, I. S., S. Anderson, C. Rowley, S. DeRada, J. Doyle, and S. R. Ramp, 2010: Comparison of upwelling and relaxation events in the Monterey Bay Area. *J. Geophys. Res.*, **115**, C06016, doi:10.1029/2009JC005483.

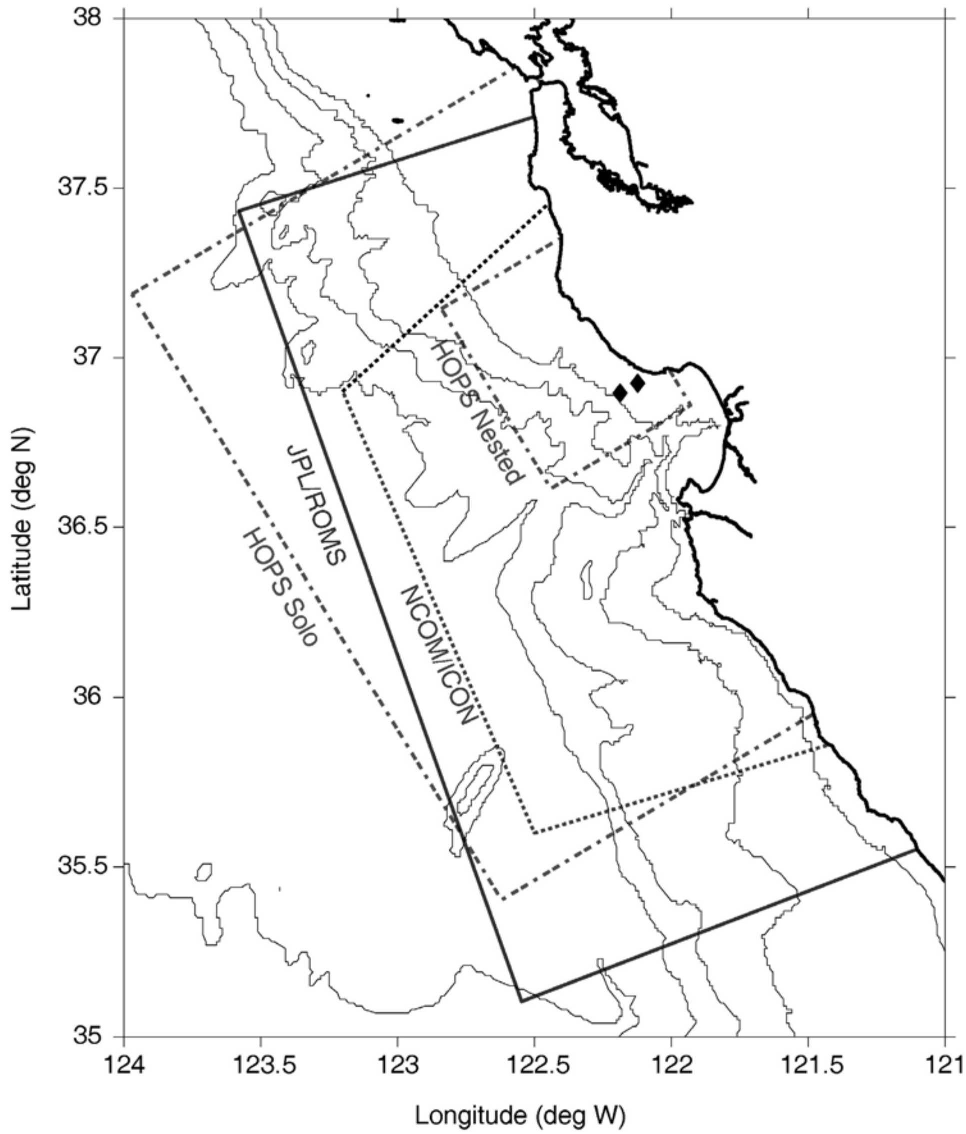

Figure 1. Adaptive Sampling and Prediction Experiment location showing the moorings (black diamonds), and the various model domains.

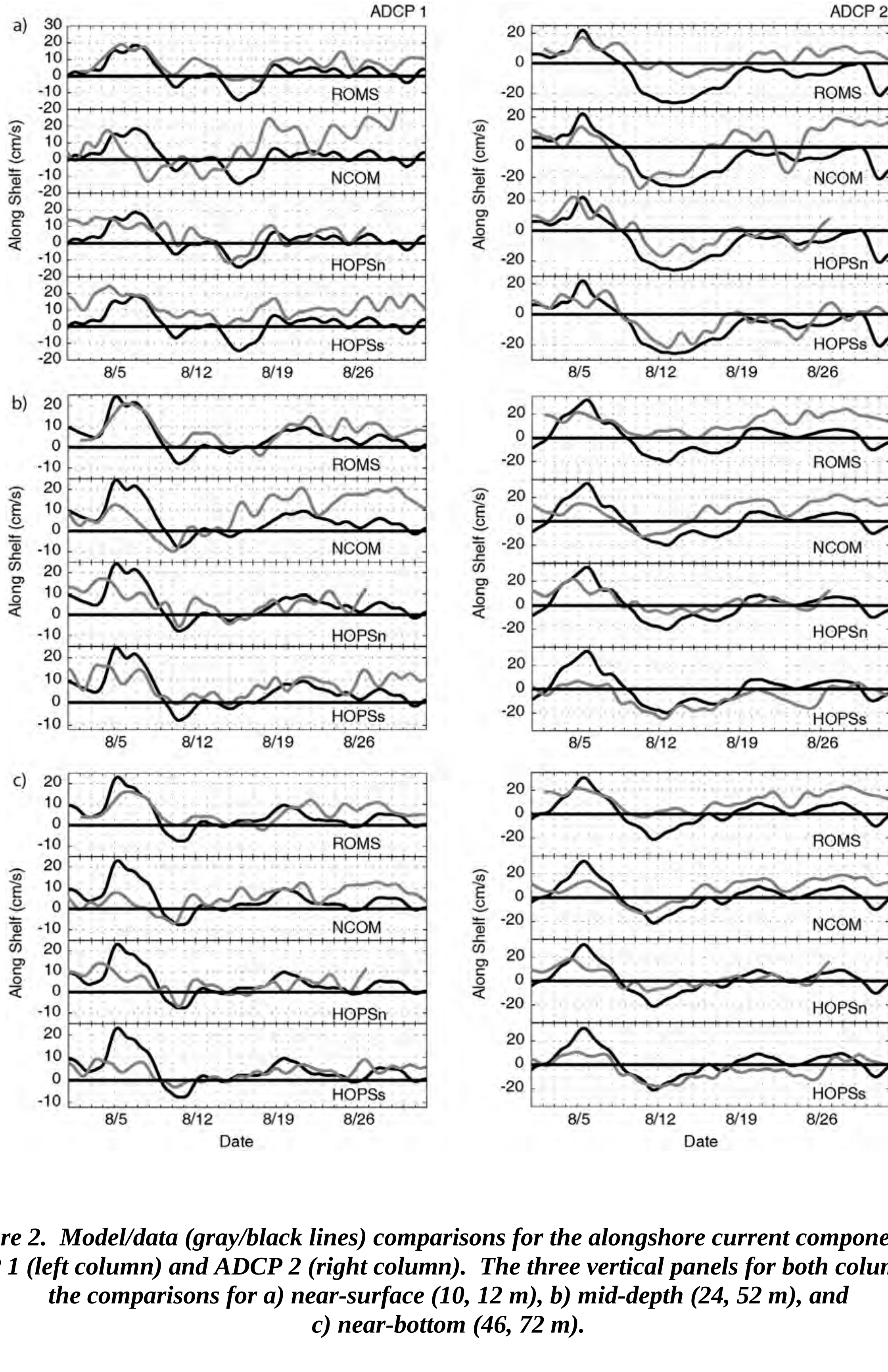

Figure 2. Model/data (gray/black lines) comparisons for the alongshore current components at ADCP 1 (left column) and ADCP 2 (right column). The three vertical panels for both columns are the comparisons for a) near-surface (10, 12 m), b) mid-depth (24, 52 m), and c) near-bottom (46, 72 m).

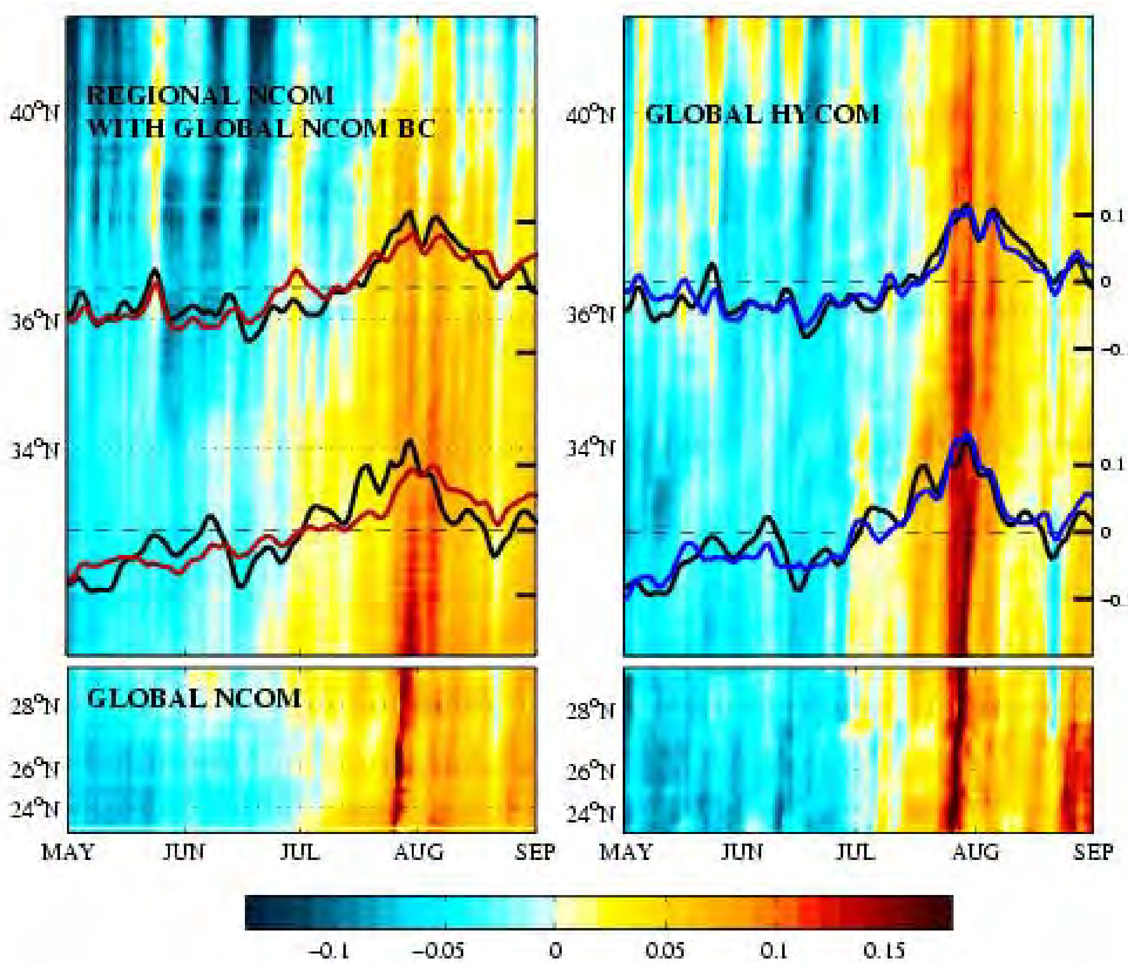

Figure 3. Sea surface height (SSH) anomalies from 24°N to 40°N as computed by (left panel) the Navy regional NCOM CCS model with global NCOM boundary conditions and (right panel) the global HYCOM model. The observed SSH from coastal sea level observations at Monterey (36° 36′ N) and San Diego (32° 43′ N) are included as the heavy black lines. Time series at the same locations sub-sampled from the two different model configurations are shown as the red (NCOM) and blue (HYCOM) lines respectively. HYCOM clearly does a better job of capturing this variability.